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**ТЕХНІКА  
ЕНЕРГЕТИКА  
ТРАНСПОРТ АПК**



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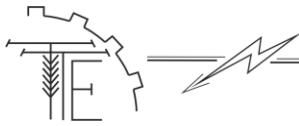
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## RESEARCH OF A FLEXIBLE SCREW CONVEYOR FOR DISPOSAL OF AGRICULTURAL LAND DAMAGED BY MILITARY ACTIONS

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*The article examines the damage and destruction of the fertile soil layer because of military operations, in particular the detonation of various types of explosive objects, and the level of contamination of agricultural soils with heavy metals and other harmful substances is studied. A method of restoring the surface of damaged lands due to bombing is proposed, which involves first cleaning the sinkholes from damaged and contaminated soil with heavy metals and other dangerous substances. If a dangerous concentration of heavy metals and other dangerous substances is detected on the surface of the funnel, then the removed contaminated layer of soil must be disposed of. During disposal of the removed contaminated soil layer, it is proposed to use a flexible screw conveyor with a sectional screw working body. The structural scheme of the experimental installation with the attachment system of the machine-tractor unit and a flexible screw conveyor is shown. The axial speed and power of transporting damaged and contaminated soil by the sectional working body of the screw conveyor along the curved route were determined. The calculation showed that the angular velocities of the adjacent sections are almost the same.*

*This study draws attention to the importance of soil condition monitoring after restoration works. Forecasting the possible environmental consequences of using the proposed methods is an important aspect to prevent further pollution. In addition, the results of the experiments can serve as a basis for the development of new cleaning technologies adapted to specific conditions. It is also important to take into account the impact of land restoration on the local ecosystem and agricultural practices, which can positively affect the restoration of soil fertility.*

**Key words:** agricultural soils, pollution, reclamation, excavation, auger, screw conveyor.

**Eq. 22. Fig. 2. Ref. 15.**

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### 1. Problem formulation

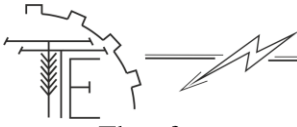
Because of military actions, the soil resources of Ukraine undergo significant destruction, deterioration of quality, strengthening of degradation processes, a number of mechanical, physical and chemical effects on the soil cover occur. Such influences lead to the destruction of the structure and functions of the soil ecosystem, lead to the deterioration of physico-geochemical properties.

Enemy aircraft and artillery have the greatest impact on agricultural land and ground cover, accounting for about 80% of the impact. Because of rocket and artillery fire, the fields are covered with craters (rifts) from the explosions of shells, mines, and rockets. The holes are of different diameters and depths.

The depth of the pits in the fields is from 30 sm (82 mm mortar) to 5 m (cruise missiles), and the soil remaining at the impact site is turbulent, subject to dynamic compaction, and also contains numerous metal fragments with remnants of explosive toxic substances, that is, they occur deterioration of the physical properties of soils, changes in particle size composition, compaction and destructuring due to a decrease in the content of agronomically valuable fractions, etc.

Other important impacts on land cover are the effects of blasting, detonation or burning of heavy machinery on agricultural land. Based on the results of the analysis of the granulometric composition of the soil, it was established that the content of physical clay decreased in the places where heavy equipment was burned and fuel and lubricant leaked.





Therefore, restoring and ensuring the conditions for preserving the fertility of the agricultural soils of Ukraine, destroyed by military actions now, is a very acute, global and urgent problem for the entire agriculture industry, which has a state priority.

## 2. Analysis of recent research and publications

In Ukraine, because of the war, more than 5 million hectares of arable land were damaged. Eruptions from explosions, trenches, toxic substances from rockets and the movement of heavy machinery all affect the quality of the soil and the products we grow. During explosions and the operation of military equipment, a large amount of toxic substances - in particular, explosives and heavy metals - enter the soil. There is chemical damage to the soil [1].

There are four types of soil destruction. Mechanical - changing the structure of the soil cover. It occurs when the fertile layer is destroyed or mixed with other layers due to the digging of trenches. After such changes, the soil loses its fertile properties, retains moisture less well and becomes less suitable for growing crops. The movement of military equipment also leads to mechanical pollution – the soil is compacted and becomes more arid. The second type is physical pollution - a change in soil properties. Military equipment causes vibrations, and explosions or fires, in addition to direct destruction, disturb the temperature regime that determines the moisture supply of plants. The third – chemical – occurs because of fuel leaks, combustion products settling on the ground from the air, and toxin from explosives in shells. However, an ammunition explosion is not only a chemical pollution, but also a mechanical one. The blast wave leads to soil erosion, which further aggravates the issue of climate change and adaptation to it [2, 3]. The fourth type is biological - the death of all living things in the soil, primarily microbiota, which is responsible for its health and fertility. It dies both from over-compaction of the soil, heat shocks, destruction of soil horizons, and from explosive toxic substances [4].

According to the results of preliminary studies, it was decided to consider all eruptions from shelling, explosion sites and the fall of unexploded rockets with rocket fuel spills, fuel spill sites from military equipment, and burnt equipment sites as dangerous for the life and health of citizens and the environment. Bursts from explosions and the area around the burrs, depending on the radius of the fragments, are contaminated with heavy metals (nickel, zinc, lead, cadmium, copper, etc.). Hazardous substances tend to enter water or plants grown on it through the soil, they can migrate in the environment and accumulate in the body of plants and animals. The entry of such substances into the human body can lead to damage to the functioning of the internal organs of a person, in particular the liver and kidneys, damage to the nervous system, and general poisoning of the body [5]. The combination of various influencing factors leads to the emergence of a cumulative negative effect. The consequences are the loss of the soil's buffering capacity for recovery, the loss of humus and a decrease in natural fertility [1].

Substances that fall into the soil during explosions remain in the pit without special treatment of the site.

If we do not carry out post-war reconstruction measures, we will get soils with flooding, salinization, erosion processes, etc. This can undoubtedly lead to destructive consequences in crop production, disturbance of soil cover, lack of natural moisture, desertification, development of wind and water erosion [6].

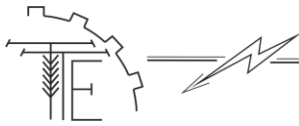
Plowing will have no effect, because the earth itself is not alive in this place. Burned earth - both the biological component of the soil, and the burnt humus, and the bacteria that should be there and make the earth alive are practically destroyed.

In order to restore the fertility of affected soils and put them into operation, it is not enough to clear the mines and then fill in all existing pits [7].

To restore areas damaged by explosions, it is necessary to remove or clean the surface layer of the soil, because in addition to chemical contamination with heavy metals, the fertile soil layer is also burned, dehydration and "sterilization" occur - both pathogenic microorganisms and useful biota die. If you do not clean the surface contaminated layer, but mechanically cover the embankment with bulldozers and graders, then the restoration of soil fertility will take tens of years, with the need for serious investments for the introduction of organic fertilizers, meliorants, phytomelioration, etc. [8, 9].

If a dangerous concentration of heavy metals and other dangerous substances is detected on the surface of the funnel, then the removed contaminated layer of soil must be disposed of. If the removed layer of the surface of the pit contains an acceptable concentration of pollutants, then the cleaned layer can be left at the bottom of the funnel [10, 11].

Shallow potholes (up to 0.5 m) can be filled with the soil mass left at the explosion site (with a permissible value of the concentration of pollutants) or mineral soil (loam, forest-like loam, sandy loam, sand), with subsequent leveling of the surface.



Deep potholes (more than 0.5 m) should be filled with soil, but the order of soil layers should be close to undamaged areas, so the pothole should first be filled with mineral soil, and the top layer (20-30 cm) should be filled with fertile black soil. If it is covered in a chaotic manner, then such a plot will be of low productivity for agricultural crops, and its restoration will require additional measures (application of organic fertilizers, meliorants, phytomelioration, etc.). On the basis of measurements of the parameters of eruptions from explosions, the working project of land management calculates the need for mineral and fertile soils.

To restore areas damaged by explosions, it is necessary to remove or clean the surface layer of the soil, because in addition to chemical contamination with heavy metals, the fertile layer of the soil is also burned, dehydration and "sterilization" occur - both pathogenic microorganisms and useful biota die [12].

To remove and clean the damaged surface layer of the soil in the hole that was formed as a result of explosions, it is recommended to use a working body that will allow mechanizing this process. This working body is attached to the boom of the excavator with a hydraulic system.

To dispose of the removed contaminated soil layer, you can use a flexible screw conveyor with a sectional screw working body, which will make it possible to reload it into the body of a truck.

Screw conveyors are used in the transportation of various types of loose agricultural materials, which include: grain, granular seed materials, clay, sand, loose soil, compound feed, mineral fertilizer granules, etc. From the analysis of literary sources, it can be concluded that the least resource-consuming technology for moving loose and lumpy agricultural materials along curvilinear routes is the use of flexible screw conveyors, which are made on the basis of separate screw sections that are hinged together [13]. In works [14, 15], the constructive, kinematic and technological parameters of screw working bodies from the point of view of their functional purpose are substantiated.

However, the existing flexible screw working bodies cannot fully satisfy the operational requirements that are put forward to these types of conveyors. The use of shaftless flexible screw spirals leads to their rapid destruction during the operation of conveyors on curved tracks, due to the occurrence of sign-changing cyclic loads. The execution of the working body in the form of a solid or sectional shaft, on which separate elements of helical ribs are located, leads to a significant complication of the design of the technological body, an increase in its material intensity, which, accordingly, causes an increase in energy consumption, as well as damage to the materials being transported.

Therefore, the task of developing new structures and substantiating the parameters of flexible screw working bodies of conveyors, which will ensure an increase in the functional and operational indicators of the process of disposal of the removed contaminated soil layer, is urgent.

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### 3. The purpose of the article

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The purpose of the study is to improve the efficiency of the operational parameters of flexible screw conveyors for the disposal of the layer of agricultural lands damaged by military actions by developing new screw working bodies

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### 4. Results of the researches

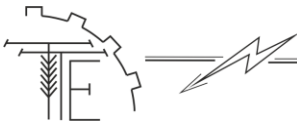
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To dispose of the removed contaminated soil layer, you can use a flexible screw conveyor with a sectional screw working body, which will make it possible to reload it into the body of a truck.

To study the process of overloading the removed contaminated soil layer in fig. 1 shows the design scheme of the experimental installation with the attachment system of the machine-tractor unit and a flexible screw conveyor.

This conveyor contains loading 1 and unloading 12 flexible casings with screw sectional hinged working bodies. Moreover, the loading and unloading casings on one side contain holes, respectively, for self-ignition of the soil and its unloading, and on the other side they are aggregated to the drive shafts of the transfer nozzle 2. Correspondingly with the flexible casings on the opposite side of the transfer nozzle 2, on the drive shafts there are sprockets 10, 13, which are kinematically connected to the intermediate shaft 11 by means of chain gears.

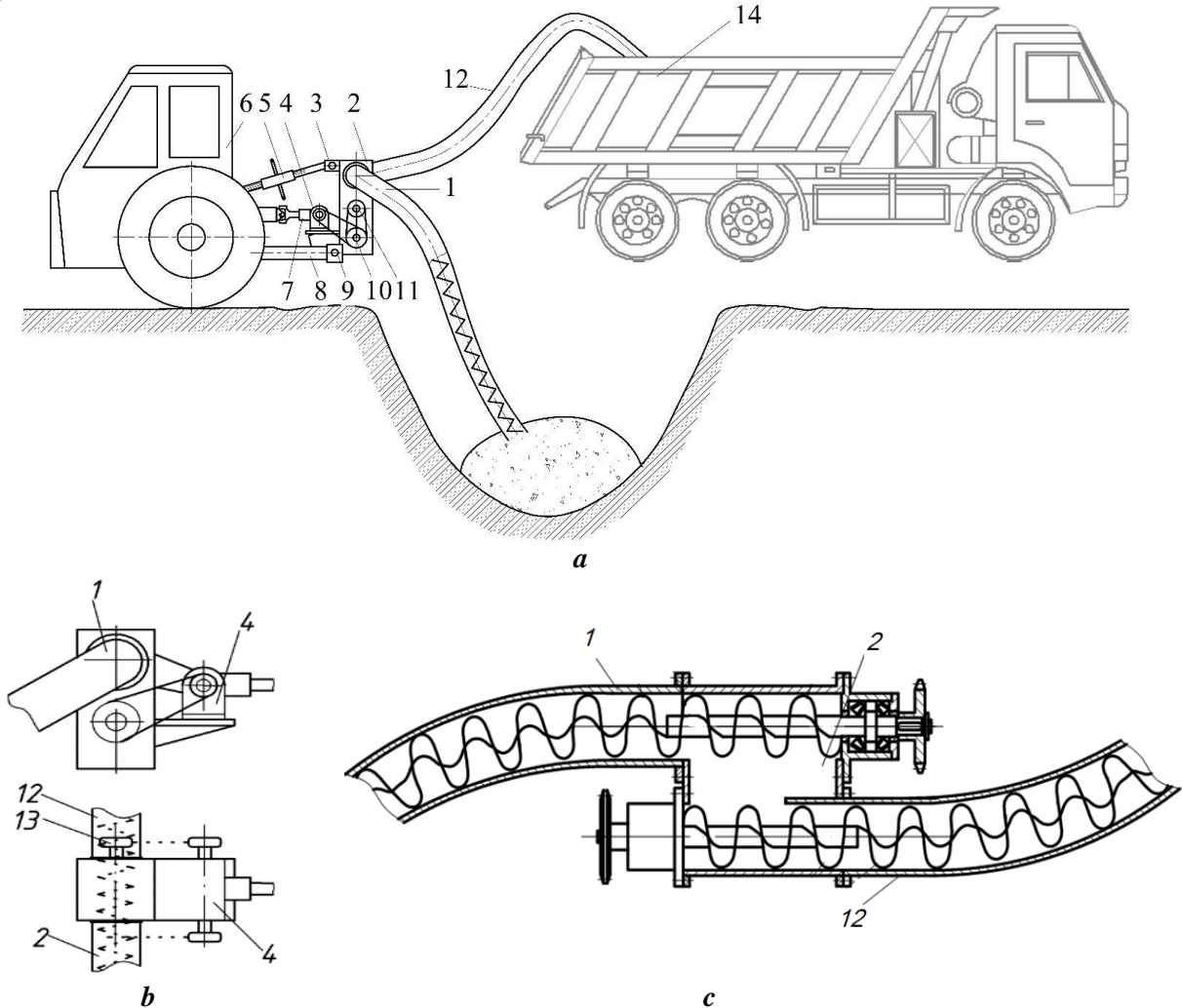
The lower 8 and upper 3 brackets are installed on the body of the transshipment nozzle, with the help of which the conveyor is connected to the central 5 and longitudinal 8 rods of the hinged system of the machine-tractor unit 6. The output shaft 10 of the unloading line is connected to the reducer 4 through a chain transmission, which, in turn, with the help of cardan transmission 7 is driven into rotational motion from the power take-off shaft of the machine-tractor unit.



To simplify the design of the drive, the intermediate shaft 11 can be the output shaft of the gearbox 4, the axis of which is located in a plane equidistant from the drive shafts of the main lines (Fig. 1, *b*). This installation is universal, since after dismantling it is installed on an autonomous frame driven by an electric motor, and the study of various working organs can be carried out in stationary conditions.

In the process of work, the kinematically connected drive shafts, intermediate shaft and power take-off shaft of the machine-tractor unit ensure the rotation of flexible helical sectional articulated working bodies.

To dispose of the removed contaminated layer of soil, a loading casing with a flexible helical sectional hinged working body is placed in the pit. The auger of the conveyor captures the cleaned soil through the self-loading hole and, when the working body rotates, transports it in the casing towards the overloading nozzle of the experimental installation and with the help of the unloading casing with a flexible screw sectional working body, to the unloading area in the truck body.

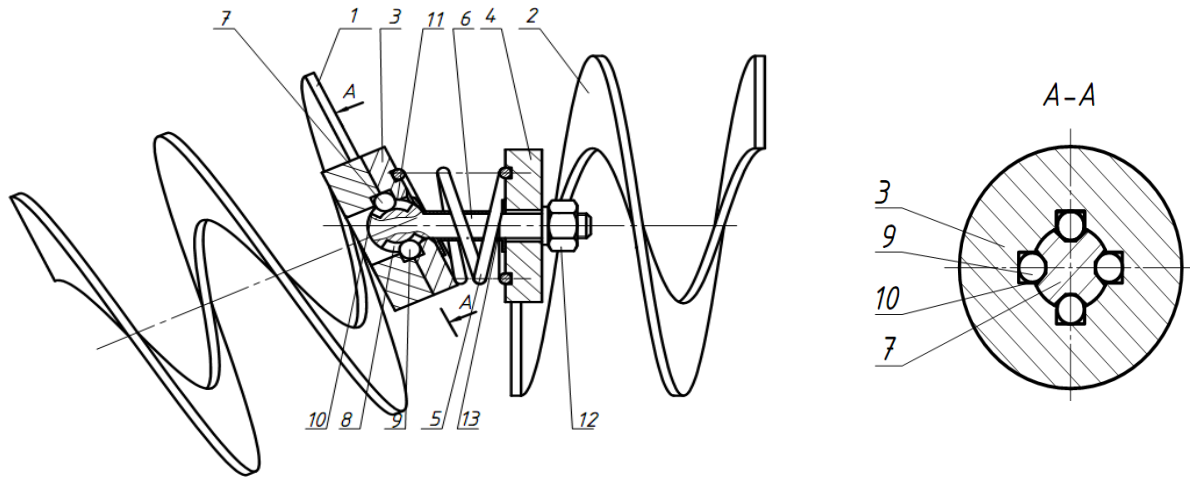


**Fig. 3. Structural scheme of the experimental installation with the attachment system of the machine-tractor unit and the truck (*a*, *b*) and flexible screw conveyor (*c*)**

In fig. 2 shows the structural diagram of such a screw sectional working body.

The section of the flexible screw conveyor body is made in the form of identical spirals 1 and 2 in thickness  $\delta$  with the number of rods of the base of the section  $n$  (Fig. 2). The ends of the spirals through the internal diameters are rigidly connected to the separate sections of the right and left mandrels 3, which are made with internal holes, and which are rigidly connected to each other through the torsion spring 5. Inside the spring, there is a hinged bolt connection made in the form of a slotted surface on the body of the bolt 6, and it is the right free end in interaction with the right inner ring connection of the mandrel.





**Fig. 2. Structural diagram of the section of the flexible screw conveyor working body**

The left end of the bolt 6 has the form of a spherical surface 7, in it there are four radiused semicircular recesses 8, which are in interaction with the balls 9, which are freely located in the inner spherical surfaces 10 of the left mandrel 3. In addition, opposite the balls 9 the spherical surface contains semicircular grooves 8, which allows the bolt 6 to rotate freely, and the spherical surface 7 of the bolt 6 to interact with the hemispherical hole 11 of the mandrel 3. The mandrel 3 consists of two halves that are rigidly connected to each other in a known way with the possibility free rotation of the spherical head 7, like a cardan transmission. The screw sections 1 and 2 are connected through a bolt connection with a nut 12. In order to seal the bolt connection, the body of the bolt 6 is covered with an elastic casing 13 to prevent loose materials from entering the friction zone.

The work of the sectional flexible screw working body is performed as follows. During the rotation of the helical section shaft, the rotational motion is transmitted from the helix 1 to the left section 3 and the balls 9 and the spherical head 7, then to the bolt body 6 with splines, to the splined sleeve 4 and the spiral 2, and the spring 5, which is with of two ends is rigidly fixed to the left 3 and right 4 bushings.

In order to study the process of movement of loose damaged soil by a flexible screw conveyor, the axial speed of loose material in a horizontal high-speed screw conveyor was determined according to the dependence:

$$V_{ax} = \frac{T_s(\omega - \omega_k)}{2\pi}, \quad (1)$$

where  $T_s$  – the pitch of the helix;  $\omega$  – angular velocity of the material;  $\omega_k$  – angular velocity of the circular component of the material movement.

Dependence (1) can be presented in the form:

$$V_{ax} = \frac{T_s \omega}{2\pi} \cdot k_v \text{ where } k_v = \frac{k_s}{\tan \theta \tan(\theta + \varphi) + 1}, \quad (2)$$

where  $\theta$  – the angle of elevation of the helix of the section;  $\varphi$  – the angle of friction of the material on the surface of the helical spiral,  $\varphi = \arctan \mu_1$ ;  $\mu_1$  – coefficient of friction of the material on the surface of the helical spiral;  $k_s$  – the coefficient that takes into account the influence of the structural design of the sectional screw conveyor,  $k_s = 0,98 \dots 0,99$ .

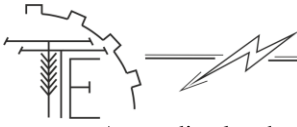
In the case of transporting the material at an angle  $\alpha$  to the horizon, its axial speed decreases, which is taken into account using a coefficient  $k_\alpha$ :

$$V_{ax\alpha} = V_{ax} \cdot k_\alpha. \quad (3)$$

For vertical placement of a screw sectional conveyor:

$$k_\alpha = 1 - S_c = 1 - \frac{\omega_k}{\omega} = 1 - \sqrt{\frac{\tan(\theta + \varphi)}{\mu_2 \rho}}, \quad (4)$$

where  $S_c$  – dynamic similarity coefficient;  $\rho$  – coefficient of speed,  $\rho = \frac{\omega^2 R_c}{g}$ ;  $R_c$  – the outer radius of the spiral,  $g$  – acceleration of free fall,  $\mu_2$  – coefficient of friction of the material on the surface of the conveyor casing.



Accordingly, the speed of axial transportation of the material through the vertical section of the flexible screw conveyor is:

$$V_{ax} = \frac{T_s \omega}{2\pi} \cdot \frac{k_s \left[ 1 - \sqrt{\frac{g \tan(\theta + \varphi)}{\omega^2 \mu_2 R_c}} \right]}{\tan \theta \tan(\theta + \varphi) + 1} \cdot \quad (5)$$

$$\psi_o V_o = \psi_\alpha V_\alpha$$

For a flexible screw conveyor, the route of which changes in space and loading occurs horizontally, with the condition of ensuring constant productivity  $Q = const$  along the route, the filling factor  $\psi$  at the loading node must take into account its change due to the change in the axial speed of transportation:

$$\psi_o V_o = \psi_\alpha V_\alpha \cdot \quad (6)$$

Hence, the value of the change  $V_\alpha$  the transportation route is extremely important.

The change in the axial speed of transport can be approximated by the curve of the species:

$$V_\alpha = V_h - (V_h - V_w) \left( \frac{2\alpha}{\pi} \right)^\lambda, \quad (7)$$

where  $V_h$  i  $V_w$  – respectively, the horizontal and vertical components of the transportation speed, at  $\alpha = 90^\circ$  can be recorded  $V_w = V_h \cdot k_\alpha$ .

According to (4):

$$V_\alpha = V_h \left[ 1 - S_c \cdot \left( \frac{2\alpha}{\pi} \right)^\lambda \right]; \quad (8)$$

$$V_\alpha = V_h \left[ 1 - \frac{1}{\omega} \sqrt{\frac{g \tan(\theta + \varphi)}{\mu_2 R_c}} \left( \frac{2\alpha}{\pi} \right)^\lambda \right], \quad (9)$$

where is a parameter  $\lambda$  depends on the rheological properties of the grain material and can be accepted as a first approximation  $\lambda = 2$ . Therefore, curve (9) can be considered a parabola and a speed dependence  $V_\alpha$  from the angle can be considered parabolic.

In the case of a freely suspended screw conveyor, the axis of the flexible screw has the form of a chain line, which varies depending on:

$$y = a \left( \operatorname{ch} \frac{x}{a} - 1 \right), \quad (10)$$

where the parameter  $a$  depends on the lifting height of the discharge opening and is determined under the condition:

$$\frac{h}{a} + 1 = \operatorname{ch} \left( \frac{l_x}{a} \right), \quad (11)$$

where  $h$  – lift height;  $l_x$  – horizontal projection of the conveyor length.

The running angle of the slope of the track can be determined from the equation:

$$\tan \alpha = \frac{dy}{dx} = \operatorname{sh} \frac{x}{a}. \quad (12)$$

where:

$$\alpha = \arctan \left( \operatorname{sh} \frac{x}{a} \right). \quad (13)$$

Therefore, for a freely suspended flexible sectional conveyor, the axial speed of movement of grain material is equal to:

$$V_{axz} = V_h \left[ 1 - \frac{1}{\omega} \sqrt{\frac{g \tan(\theta + \varphi)}{\mu_2 R_c}} \left( \frac{2 \arctan \left( \operatorname{sh} \frac{x}{a} \right)}{\pi} \right)^\lambda \right]. \quad (14)$$

Fill factor  $\psi_\alpha$  in the most unfavorable section should not exceed  $\psi_\alpha \leq 0,7$ . Accordingly, in the loading zone, the rational loading coefficient should be chosen according to (6):



$$\psi_o = \frac{\psi_\alpha V_\alpha}{V_o} = 0.7 \cdot k_\alpha \cdot \quad (15)$$

The productivity of the screw conveyor is determined by the dependence:

$$Q = \pi \psi_o \cdot V_{ax\alpha} (R_k^2 - R^2), \quad (16)$$

where  $R_k$  – radius of curvature of the highway.

The power of a screw conveyor with a variable transport route is determined by the dependence:

$$N = Q \cdot L \cdot w, \quad (17)$$

where  $w$  – specific energy intensity of transportation:

$$w = \frac{\mu_2 \cdot \rho \cdot R_c^2 \cdot \omega_f^2 \cdot \omega \cdot \cos \beta}{V_f}, \quad (18)$$

where  $L$  – length of transportation;  $\omega_f$  – angular velocities of adjacent sections,  $V_f$  – axial speed of material transportation by the articulated-sectional working body of the screw conveyor along a curved track;  $\beta$  – angle of inclination of the trajectory of material transportation.

The axial speed and power of material transportation by the sectional screw working body of the screw conveyor along the curved route were determined. From the calculation, it was established that the angular velocities of the adjacent sections are almost the same.

Elementary capacity of transportation of grain material for a flexible sectional screw conveyor with a variable track on the site  $dl$  determined by the formula:

$$dN = Q \cdot w(l)dl, \quad (19)$$

where

$$w(l) = \frac{\mu_2 \rho R_c^2 \omega \omega_f^2(l) \cos[\beta(l)]}{V_f(l)}$$

The angular velocity of the flow in accordance with (1) is determined by the dependence:

$$\omega_f = \omega - \frac{2\pi V_{ax\alpha}}{T_s}. \quad (20)$$

The angle of inclination of the trajectory of material transport  $\beta$  is determined from the dependence:

$$\tan \beta = \frac{V_{ax\alpha}}{\omega_{f\alpha} R_c} = \frac{V_{ax\alpha}}{\left[ \omega - \frac{2\pi V_{ax\alpha}}{T_s} \right] R_c}. \quad (21)$$

Axial speed of material transportation by the articulated and sectional working body of the screw conveyor along a curved track  $V_f$  we take equal  $V_{ax\alpha}$ .

Therefore, the capacity of transportation of grain material for a flexible sectional screw conveyor with a variable route is determined by the formula:

$$N = Q \int_0^L w(l)dl = Q \mu_2 \rho R_c^2 \omega \int_0^L \frac{\left( \omega - \frac{2\pi V_{ax\alpha}}{T} \right)^2 \cos \beta}{V_{ax\alpha}} dl. \quad (22)$$

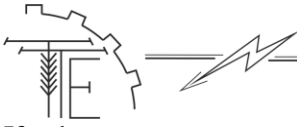
From dependence (22), we see that when the angle of inclination of the trajectory of the material transport increases  $\beta$ , the values of the energy-power parameters of the conveyor increase, and the increase in the pitch of the screw turns in the direction of the movement of the material leads to a decrease in the energy-power parameters of transportation.

## 5. Conclusions

The damage and destruction of the fertile soil layer as a result of military operations, in particular the detonation of various types of explosive objects, was analyzed, and the level of contamination of agricultural soils with heavy metals and other harmful substances was studied.

A method of restoring the surface of damaged lands due to bombing is proposed, which involves first cleaning the sinkholes from damaged and contaminated soil with heavy metals and other dangerous substances.





If a dangerous concentration of heavy metals and other dangerous substances is detected on the surface of the funnel, then the removed contaminated layer of soil must be disposed of.

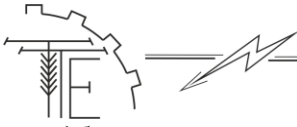
During disposal of the removed contaminated soil layer, it is proposed to use a flexible screw conveyor with a sectional screw working body. For this, a structural scheme of an experimental installation with a hitch system of a machine-tractor unit and a flexible screw conveyor was developed. The axial speed and power of transporting contaminated soil by the sectional working body of the screw conveyor along the curved route were determined. The calculation showed that the angular velocities of the adjacent sections are almost the same.

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### ДОСЛІДЖЕННЯ ГНУЧКОГО ГВИНТОВОГО КОНВЕЄРА ДЛЯ УТИЛІЗАЦІЇ ПОШКОДЖЕНОГО ВІЙСЬКОВИМИ ДІЯМИ ШАРУ ЗЕМЕЛЬ СІЛЬСЬКОГОСПОДАРСЬКОГО ПРИЗНАЧЕННЯ

В статті досліджено пошкодження та знищення родючого шару ґрунту внаслідок воєнних дій, зокрема детонації різного роду вибухових предметів, та вивчено рівень забруднення ґрунтів сільськогосподарського призначення важкими металами та іншими шкідливими речовинами. Запропоновано метод відновлення поверхні пошкоджених земель внаслідок бомбардування, який



передбачає спочатку очищення воронки від пошкодженого та забрудненого ґрунту важкими металами та іншими небезпечними речовинами. Якщо на поверхні воронки виявлено небезпечну концентрацію важких металів та інших небезпечних речовин, то знятий забруднений шар ґрунту необхідно утилізувати. Під час утилізації знятого забрудненого шару ґрунту запропоновано використовувати гнучкий гвинтовий конвеєр з секційним шнековим робочим органом.

Показана конструктивна схема експериментальної установки з начійною системою машинно-тракторного агрегату та гнучким гвинтовим конвеєром. Визначено осьову швидкість та потужність транспортування пошкодженого та забрудненого ґрунту секційним робочим органом гвинтового конвеєра криволінійною трасою. Розрахунок показав, що кутові швидкості сусідніх секцій майже однакові.

Дане дослідження звертає увагу на важливості моніторингу стану ґрунтів після проведення відновлювальних робіт. Прогнозування можливих екологічних наслідків використання запропонованих методів є важливим аспектом для запобігання подальшого забруднення. Окрім того, результати експериментів можуть слугувати основою для розробки нових технологій очищення, адаптованих до специфічних умов. Важливо також врахувати вплив відновлення земель на місцеву екосистему та агрокультурні практики, що можуть позитивно позначитися на відновленні родючості ґрунтів.

**Ключові слова:** ґрунти сільськогосподарського призначення, забруднення, рекультивация, вирва, шнек, гвинтовий конвеєр

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